



**We demonstrate liquid core waveguides defined by UV to enable selective water infiltration in nanoporous polymers, creating an effective refractive index shift  $n=0.13$ . The mode confinement and propagation loss in these waveguides are presented.**

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# Experimental quantum averaging of squeezed quadratures

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**Abstract:** We demonstrate an averaging process, corresponding to the harmonic-mean, that average quantum noise sources better than the basic arithmetic-mean strategy. Using simple linear optics, homodyne detection and feedforward, and it is tested on squeezed states.

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## 1. Introduction

Squeezing has been recognized as the main resource for quantum information processing [1] and an important resource for beating classical detection strategies [2] and also for fundamental test of quantum mechanics. It is therefore of high importance to reliably generate stable squeezing over longer periods of time. In this contribution we propose and experimentally demonstrate the stabilization of two squeezed light resource through an effective average algorithm, known as the harmonic mean.

To explain the protocol we consider the following problem. Two squeezed light resources produce different and unknown degrees of squeezing, and we aim to optimize the squeezing into a single mode to be used in an application. Since the degrees of squeezing of the two sources are unknown it is not possible just to pick the source with highest squeezing. However, one selection strategy is to randomly choose one of the sources which will generate a source with quadrature variance  $V_A = (V_1 + V_2)/2$ , where  $V_1$  and  $V_2$  are the squeezing variances of the individual sources. This averaging procedure (yielding the arithmetic mean of the inputs) can be improved by using an averaging method that produces the harmonic mean:  $1/V_H = (1/V_1 + 1/V_2)/2$ . We propose and experimentally implement a procedure to execute such an averaging algorithm. The strategy is to interfere the two squeezed light states on a beam splitter and probabilistically herald one output based on the homodyne measurement result of the other output. If the measurement outcome of the homodyne measurement lies within a certain interval the state is kept, otherwise it is discarded. We implement experimentally the probabilistic harmonic-mean protocol, and show how the amplitude noise variance is stabilized against multiplexed noise sources with both uncorrelated and partly correlated noise.

## 2. Experimental Realization of the harmonic-mean

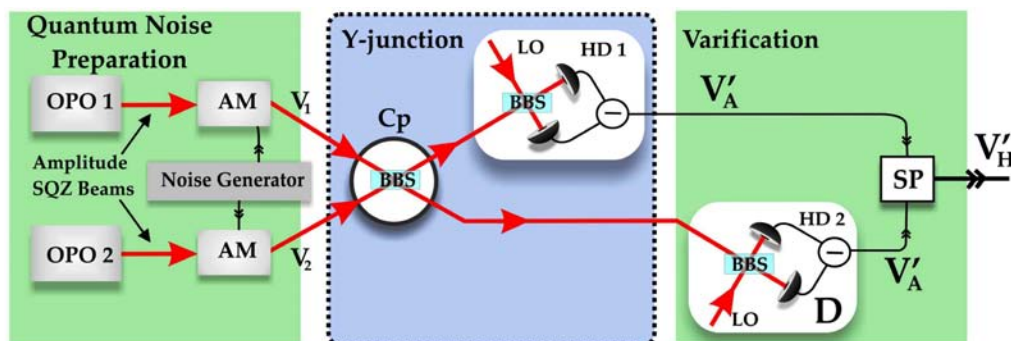


Fig.1. Schematics of the experimental QECC setup

The averaging procedure for a single quadrature can be realized using a single beam splitter followed by homodyne measurement and feed-forward as shown in Fig. 1 and as we coin a Y-junction. If the input squeezing variances are known, the protocol can be deterministic where all quadrature measurement outcomes are used to drive a displacement operation in the other output. However, since the input states have unknown squeezing degrees the deterministic protocol can not be used. By resorting to a probabilistic protocol, where the output state is selected based on the quadrature measurement outcomes, it is however possible to construct the harmonic mean without knowing the input variances as explained above.

The schematics of our experimental setup are depicted in Fig. 1. The setup consists of three stages; a quantum noise preparation stage, the Y-junction and the verification stage. The quantum noise is prepared using two OPOs and two amplitude modulators (AM). The detection is achieved by homodyne detections. The two amplitude squeezed beams are first sent through the AMs, where the uncorrelated and partly correlated amplitude noise is generated, and then mixed with a relative phase of 0 on a balanced (50/50) beam-splitter (unitary coupler, Cp). The simplest arithmetic-mean of two variances just mixes simply coherently the noisy sources with the symmetrical passive linear unitary coupler Cp. From one output port of the coupler the arithmetic-mean can be found. From the other output port information is gained about the noise of the two beams and subsequently post-selected and used to herald the remaining state which is done electronically. The best result is obtained if the post-selection is chosen close to zero.

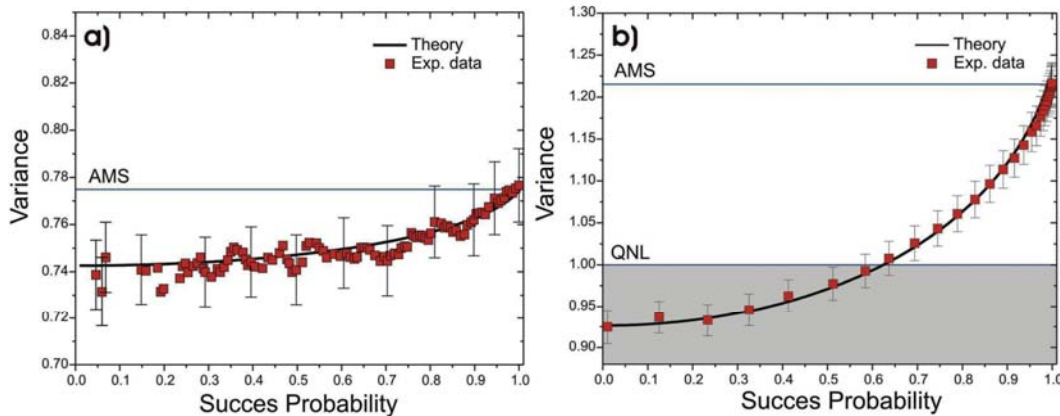


FIG. 2: Results of the averaging of quantum noise sources. The upper horizontal (blue) line corresponds to the arithmetic mean and theoretical simulations are plotted by the black curves. The success probability is a function of the size of the post-selected interval.

The experimental results for the uncorrelated quantum noises are shown in Fig. 2. The results for two amplitude squeezed beams with variances  $V_1 = 0.64$  and  $V_2 = 0.90$  relative to the quantum noise limit (QNL) is depicted in Fig. 2a. The harmonic-mean method gives  $V_H = 0.75$  and the arithmetic-mean method gives  $V_A = 0.77$ . In this case the improvement of the amplitude noise using the harmonic-mean method is very small and is basically within the measurement uncertainty. In Fig. 2b the two input beams have the variances  $V_1 = 0.62$  and  $V_2 = 1.83$  and we find that the arithmetic-mean method ( $V_A = 1.2$ ) is not able to reduce the noise below the QNL. However, we see that for a success probability around 0.6, the harmonic-mean method is already below the QNL. For a success probability around 0.1 the harmonic-mean method gives  $V_H = 0.9$ . This shows that the universal harmonic mean can stabilize very fragile and unstable quantum noise sources below the QNL against large amounts of classical excess noise. In all cases based on the experimental parameters, theoretical simulations are plotted by the black curves and show a very good agreement with the experimental results.

In this contribution we will also present results for partially correlated noise and it clearly demonstrates that the effect of averaging using the harmonic-mean is enforced if the noises are partially correlated.

### 3. References

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